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Residual Nitrogen As it Affects Soil Fertility Under Irrigated Agriculture in a Tropical Wet-Dry Climate

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RESIDUAL NITROGEN AS IT AFFECTS SOIL FERTILITY UNDER IRRIGATED AGRICULTURE IN A TROPICAL WET-DRY CLIMATE

by

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ABSTRACT

Residual Nitrogen as It Affects Soil Fertility

Under Irrigated Agriculture in a

Tropical Wet-dry Climate

by

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In the Zapotitan Valley near San Andres, El Salvador, Central America, an experiment was conducted to determine the availability of residual soil N to corn grown during the rainy season. This was an extension of an experiment conducted during the preceding dry season. The variables of the dry season experiment were irrigation method, crop, and rate of fertilizer N application. Soil NO_3-N and NH_4-N were determined by soil sample analysis to a soil depth of 120 cm by 30 cm depth increments. The samples were taken at the end of the dry season experiment and again at harvest time of the wet season experiment. Yield of corn grown during the rainy season was measured. The results indicate the following: (1) soil NO_3-N alone was an efficient indicator of residual soil N; (2) there was a linear increase of soil NO_3-N with N applied four months previously at the beginning of the dry season crops; (3) soil sampled to the 30 cm depth was sufficient to estimate availability of the residual N; (4) corn yields increased linearly with the increase of soil NO_3-N; (5) the measurement of residual soil NO_3-N can be used as a soil text index in connection with N prediction equations for estimating fertilizer N requirements. The measurements of soil NO_3-N can, therefore, increase the efficiency of fertilizer use in a wet-dry tropical climate.

(57 pages)

INTRODUCTION

Central America is in many ways typical of other tropical areas in the world that have two distinct seasons--a wet season with rainfall varying from inadequate to excessive, and a dry season with virtually no rain. Like other such areas, Central America is heavily populated and has increasing food needs that must be met if food production is to keep up with the demands. The best hope available for increasing production is through irrigation development so that land can be cropped on a year-round basis. A pooled effort in adapting good irrigation farming practices is greatly needed. It is felt by many agriculturalists that only through a pooled research effort to adapt better farming practices to a large segment of the world can the food demand be met.

Central America is composed of an area of about 580,000 square kilometers (km) with a population of about 18,000,000 people. This makes an average of about 31 people per square km. The highest population density is in El Salvador with about 177 people per square km and the lowest is in British Honduras with about 4.5 people per square km. Since 1950 the human population has grown at an annual rate of approximately 3.2 percent (Battelle, 1969; and Nathan, 1969).

By 1980 the population is expected to be over 23 million. Projected increases in demand for agricultural products exceed supply projections by 0.5 to 1.5 percent. This means that larger imports can only be avoided by introducing technological innovations (Nathan, 1969). With a limited area for expansion in crop production, this places a heavy demand on agriculture; it will require an intensive utilization of agricultural lands on a year-round basis.

Rainfall in Central America is distributed over about a six-month period usually beginning in May and ending in October. The annual rainfall varies from about 3,000 mm in the higher elevations to about 500 to 1,500 mm in the central and coastal regions. During the remaining six-month period, Central America receives virtually no precipitation.

Irrigated agriculture is not practiced extensively. With irrigation, crop production can be continuous, and not limited to rainfall period of quantity.

Crop yields are dependent upon soil nitrogen availability. Usually that made available by nature must be supplemented by man. To the small farmers of Central America, who form a large percent of the agricultural sector, fertilization represents a sizable investment. The use of commercial fertilizer is an accepted practice, but it is practiced to only a limited extent because of the difficulty in financing fertilizer purchases. Even with adequate financing, the success of a farm enterprise, large or small, is dependent upon the management of the many production factors involved. One of the most important production factors in irrigated agriculture is the efficient use of nitrogen fertilizer.

Considering nitrogen from the standpoint of pollution control, economic waste, and efficient use for greater food production, the estimate of seasonal carryover of available soil nitrogen is a very important essential.

LITERATURE REVIEW

"When considered in light of the total quantity required by plants and the frequency with which it is a growth-limiting factor, nitrogen is probably the most important nutrient element in soils" (Hausenbuiller, 1972, p. 243).

This statement, no doubt, expresses the opinion held by most people connected with agricultural production. It also implies the important role nitrogen (N) plays in meeting the continually increasing demand placed upon agriculture for supplying the world's food needs. N is most abundant in soils in the organic form, but is most available to plants as ammonium (NH_4) and nitrates (NO_3) salts. Shrader et al. (1972) show the plant preference to NH_4-N and NO_3-N individually and in combinations. However, it is well-established that nitrification takes place rapidly under favorable crop growing conditions making NO_3-N the principal form of readily available N. Being highly soluble, NO_3-N may be taken up from the soil by plants and also may be leached by percolating water. The latter creates many problems related to its efficient use. N fertilization improves plant and animal nutrition but it can lead to some environmental pollution. Viets and Hageman (1971) point out that these problems have prompted a great deal of research, and even though there are some groups so concerned about pollution that they would impose N use limitations, there is no indication of widespread upward trends of NO_3-N concentrations in foods, feeds, or surface and/or ground water.

It has been indicated by some researchers that an equilibrium exists in soils between the amount of N returned to the soil as organic

N and the amount taken up by the crop. This is implied only under ideal conditions. That is, continuous cropping when all of the crop is returned to the soil as organic material and no N losses occurring by leaching or denitrification. If part of the crop is harvested, then an equivalent amount of N removed in the harvested crop must be returned to the soil in order to maintain the equilibrium. The same is true if part of the mineralized N is lost through leaching or denitrification. This fact suggests a need for an index of the availability of soil N (Bartholomew, 1972; Dahnke and Vasey, 1973; James, personal communication).

The equilibrium concept suggests that under continuous cropping or rotation sequence (without legume), N release from mineralization would, in time, become near constant. Edwards et al. (1973) studied N uptake efficiency by corn, wheat, sorghum and sudax. They determined the NO_3-N content of the soil to a depth of 120 cm before planting and again after harvest. Adding the soil NO_3-N before planting to the N fertilizer applied amounted to the nitrogen available to the crop as recorded on their N balance sheet. The amount of N found in the harvested crop plus the soil NO_3-N after harvest was recorded as N accounted for. The differences were recorded on the N balance sheet as plus or minus. These differences were, in general, small and in some instances near zero. These trials did not take into account NO_3-N release during the growing season from mineralization of organic matter.

Quoting Dahnke and Vasey (1973)

> Nitrogen availability indexes are a measure of the potential of a soil to supply N to plants. This type of is practical only in situations where one is confident that very small (less than 20 kg of NO_3-N per hectare in the top 61 cm of soil) or constant amounts of residual N are in the soil at planting time. (Dahnke and Vasey, 1973, p. 99)

More efficient use of N hinges primarily upon estimating the amount of available N in the soil, whether it comes from mineralization of organic materials alone, or as an accumulation of NO_3-N from both mineralization and residual commercial fertilizer N. Many biological and chemical methods have been proposed for the determination of these estimates.

A biological method for determining an N fertility index which is now being used extensively by growers has been worked out by researchers at California (Ulrich et al., 1959). They maintain that soil tests for N availability are difficult to interpret because of necessary considerations of crop, soil type and climate. Their method involves plant tissue analysis for N at various time intervals. By comparing the nutrient concentrations to established nutrient critical levels for the plant, the nutrient status of the plant can be ascertained, and corrected by fertilizer N applications as needed.

Incubation tests have been studied for years as a possible basis for predicting N availability from the mineralization of organic matter. Bremner (1965) discusses these methods and points out that the most satisfactory are those involving estimation of the mineral N formed when soil is incubated under conditions which promote mineralization.

Stanford, Carter and Smith (1973) demonstrated that NO_3-N could be estimated reliably from amounts of N mineralized during two-week incubations followed preliminary incubations of 1 to 2 weeks.

Bremner (1965) points out that the chemical approach to obtaining a laboratory index of N availability is the most attractive because these methods are usually more rapid, more convenient, and more precise than biological methods.

Fitts and Bartholomew (1967) state that the objective of soil testing is to gain information for use as a guide in the proper rates of fertilizers in order to obtain the greatest economic return for the money invested in crop production. In irrigated agricultural areas where rainfall does not impose a threat to N losses by leaching, reliable soil test indices have been proposed for various crops.

Nelson, Early, and Mortensen (1965, 1965, 1966) found high correlations (range up to r^2 - 0.90) between soil test NO_3-N (in the 0-6 foot or less soil) and crop yields for wheat, corn, and hops under irrigated conditions in Central Washington. Accordingly, they proposed soil test indices of NO_3-N as a means of estimating fertilizer N requirements for these crops. James (1971) and James et al. (1971), from field experiments conducted in Central Washington, found a high correlation between total sugar produced by sugarbeets and the soil test NO_3-N. A total of 86 fields were sampled and analyzed for NO_3-N. There was an accumulation of NO_3-N which ranged from approximately 23 to 654 lbs per acre. A soil test N index analogous to that of Nelson, Early, and Mortensen (1965, 1965, 1966) was proposed for this crop as a means of estimating fertilizer N requirements.

In Iowa under non-irrigated conditions, White, Dunenil, and Pesek (1958), and White and Pesek (1959), characterized increased quantities of soil N resulting from N applied to corn one year previous, both as to form and location in the soil profile. They found the residual fertilizer N to be chiefly in the form of NO_3-N in the 6-21 inch layer. No appreciable quantity of NH_4 was found. They concluded that soil NO_3-N levels were a reliable means of estimating residual soil N. There were correlations as high as .945 between N yield of oats and the NO_3-N in the soil profile 0-21 inch layer.

Leggett (1959) under non-irrigated conditions in Eastern Washington reported on 62 experiments with winter wheat. The relationship between available nitrogen (NO_3-N and fertilizer N) and the yield of wheat had a correlation coefficient of 0.74. NO_3-N was measured by soil sample analysis to a soil depth of 6 feet. The average yield from the unfertilized plots in the experiments conducted on fallowed land correlated with soil NO_3-N content with an r value of 0.71. Using the NO_3-N soil test plus the available soil moisture made it possible to calculate N fertilizer needs.

Stanford (1966) developed a nitrogen prediction equation for corn which involves the ability of the soil to supply N during the growing season as well as the amount of residual NO_3-N. Also involved was the amount of N contained in the above ground dry matter and fertilizer use efficiency. The equation predicts the amount of N required to produce a given yield of corn.

Waugh, Cate, and Nelson (1973) discussed the development and use of linear response and plateau models. This concept first separates the soil tests into two categories through extensive soil analysis and corresponding crop yields. The two categories are separated by a quadrant superimposed over the scatter diagram in such manner that the maximum number of points possible appear in the positive quadrants. Thus, the vertical line of the quadrant intersects the soil test axis of the scatter diagram establishing the point at which yields fail to increase further. The soil test at this point was termed the Cate-Nelson critical level. Fertilizer experiments are then conducted within each soil-crop category to establish the threshold yield for each nutrient (the crop yield at zero fertilizer level with all other nutrients adequately supplied), and the plateau yield for each nutrient (the point at which yields fail to increase further). With these two levels established for a soil crop category, an optimum combination of required fertilizer nutrients can be predicted.

A soil sampling technique worked out by Leggett (1959) and Nelson, Early, and Mortensen (1965) involves sampling the soil profile by 30 cm increments to a depth of 180 cm, or to a limiting layer, whichever occurs first. The samples were kept at low temperatures using dry ice to minimize mineralization. In more recent studies the soil samples were immediately dried with forced air at 50 C.

Nelson and Bremner (1971) investigated methods of preparation for storage and storage of soil samples for N determination. They found that changes in organic N could be reduced significantly when the samples were air dried in ammonia-free air and stored in air tight containers.

From the foregoing discussion it is apparent that N fertilizer applied to crops in one season has significant beneficial effects to crops grown in subsequent seasons. This can be inferred from the great amount of work that has been done to evaluate residual N.

Objective

The objective of this thesis is to evaluate the amount and availability of residual N in an experiment conducted in the Zapotitan Valley of El Salvador, Central America. The amount and availability of residual N will be expressed in terms of soil chemical analysis and crop performance.

MATERIALS AND METHODS

Site description

El Salvador, Central America, has two distinct seasons typical of all Central America. The rainy season starts with May and ends with October. The balance of the year is dry. The annual precipitation is 1,500 to 2,500 mm with about 95 percent occurring during the rainy season. In the Zapotitan Valley near San Andres, the rainfall average per year is about 1,880 mm. The lowest precipitation for the rainy season occurs in May with an average of about 155 mm followed by successive monthly averages of 314, 330, 317, 400, and finally for October 241 mm (Istomo CentroAmericans, 1971).

Field plot design

During the irrigation season of 1972-73 (Time 1) an experiment was set up on the experimental farm of the National Center of Agricultural Technology (CENTA) of El Salvador located in the Zapotitan Valley near San Andres. The soil at this site is a sandy loam to varying depths of 30 to 50 cm. It is underlain by coarse black sand (volcanic ash) with intermittent and non-continuous hard semipervious layer, partially cemented or fused. The total depth of the soil to basalt bedrock is several meters. The experimental variables were: kind of crop (corn and tomatoes); irrigation method (furrow, sprinkler, and drip); and N fertilizer rate (75, 225, 375, and 525 kg of N/ha in the form of NH_4NO_3 (34% N).

The experimental design consisted of 6 blocks, two for each irrigation method; within each irrigation method one block was for corn and the other for tomatoes. The individual block contained the four N fertilizer treatments. Each individual plot was 4.8 meters wide and 12 meters long. This permitted six rows of corn at 80 cm row width or four rows of tomatoes at 120 cm.

After the harvest of the dry season experiment (Time 1) and before the rainy season began, the above ground corn and tomato residues were cut and removed from the field. Soil samples were then taken from each N plot in the following manner: from two randomized locations within the plot, three borings were made by 30 cm depth intervals to 120 cm. The first of each of the three borings was located in the center of the previous crop row. The second and third were located at about one-third and two-thirds of the row width on about 45° diagonals between the rows. The soil from the first 30 cm of the six borings was combined into one composite sample. The second 30 cm of soil from each of the six borings was combined into a second composite sample and so on for the third and fourth depth intervals. The soil samples were placed in plastic containers, sealed, and then placed inside of an ordinary paper bag and stored about 30 days, pending laboratory analysis. At the time of sampling, the soil was relatively dry, the top 30 cm being well below permanent wilting point. It was therefore apparent that mineralization during the storage period would be minimal or non-existent. Just prior to harvest (about midway through the rainy season) the fertilizer N plots were sampled in a similar manner as described above, but limited to one fertilizer replication within each irrigation method and crop block. These samples were placed in a greenhouse and spread out where they dried to air dry conditions in about 24 hours. The samples were then placed in plastic bags and stored for about 30 days before being analyzed at the same laboratory. The soil samples were delivered to Guatemala City for NO_3-N and NH_4-N analyses at the Ministry of Agriculture Soils Laboratory under the direction of Dr. J. L. Walker, North Carolina State University. The recommendations from the literature on soil sampling and preparation were followed as closely as prevailing conditions and materials would permit.

On June 4, near the beginning of the rainy season (Time 2), corn variety H-3 was planted over the entire experimental area without fertilizer being applied except for three buffer strips between the sprinkler irrigation blocks of the dry season (Time 1) experiment.

The buffer strips were fertilized with N at the rate of 200 kg/ha and P at 30 kg/ha. All of the P and one-third of the N was applied by side-dressing 5 cm deep and 8 cm to the side of the planted row at planting. A second application of one-third of the N was made when the corn was about 30 cm in height. The final one-third of the N was applied at tassel stage. The corn yields from these plots served as benchmark yields for the rainy season (Time 2) experiment.

The corn from each of the individual plots was harvested from the four center rows 10 meters (m) in length. The corn was dried and moisture readings on shelled corn were made. Weight of shelled corn was adjusted to 12 percent moisture content and recorded in kilograms per plot.

Residual NO_3-N, as determined by soil sample analysis, at the termination of the two crop seasons were compared. They were studied on the basis of their relation to corn yields, method of irrigation, previous crop, and N rate.

RESULTS AND DISCUSSION

Residual NO_3

Figure 1 shows the ppm of residual NO_3-N, NH_4-N, and NO_3-N + NH_4-N at the four fertilizer N treatment levels. NH_4-N changed very little while NO_3-N and total -N are both linear and parallel to each other. The average NH_4-N content of all the soil samples at the end of the rainy season (Time 2) experiment was 2.86 ppm. These results are in agreement with studies cited previously (White, Dumenil, and Pesek, 1958; White and Pesek, 1959). Because of the small and constant relationship between NH_4-N and NO_3-N alone was used as the estimator for residual N. Treatment effects were significant at one percent level (see Appendix A, Table 7).

There was a linear increase of NO_3-N in the soil with the rate of fertilizer applied for both crops as shown in Figure 2. There was a significant difference between the residual NO_3-N for Crop 1 and 2 (see Appendix A, Table 7). Crop 2 (tomatoes) was planted at 120 cm row spacing with 50 cm between plants in the row. The corn (Crop 1) was planted at 80 cm row spacing with about 20 cm spacing within the row. Some of the tomato plants died, leaving a population percentage between 65 and 85 percent. These two considerations could explain some of the residual NO_3-N differences observed. The average residual soil NO_3-N for each fertilizer level and soil depth are shown in Table 1 and graphically in Figure 3. These data are significant at the one percent level (see Appendix A, Table 7). With each fertilizer rate the highest accumulation of NO_3-N was in the first 30 cm. There was a leveling off

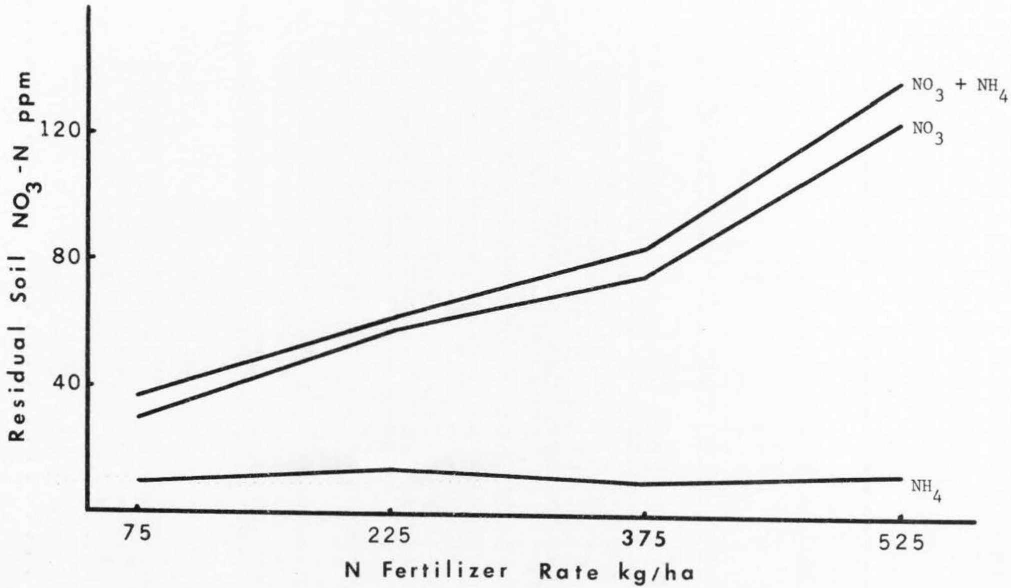

Figure 1. Residual soil NO_3, NH_4, and $NO_3 + NH_4$ in relation to previously applied fertilizer N. Each point is the average of four replication, two crops, three irrigation methods, and the total of four soil depths.

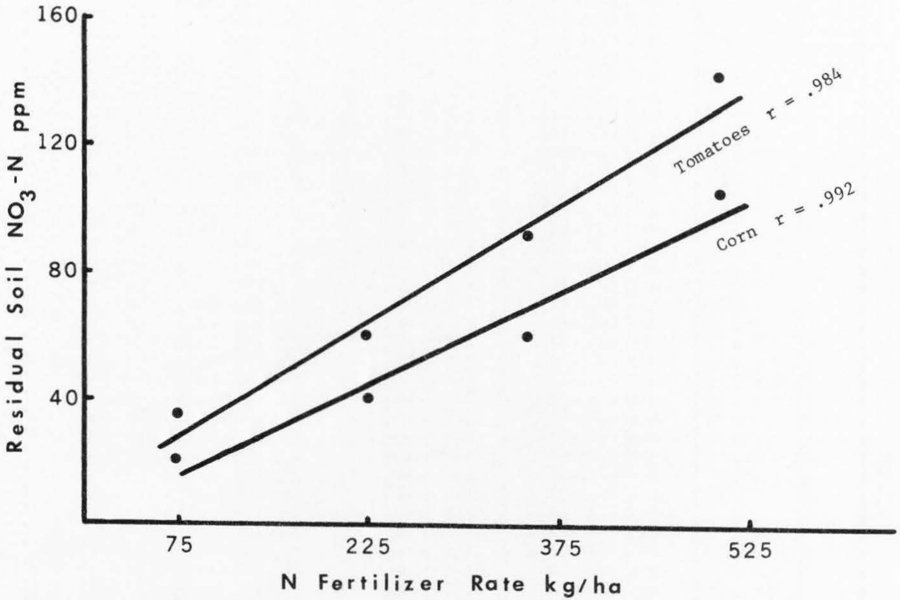

Figure 2. Residual soil NO_3-N as related to previous crops and fertilizer rate. Each point is the average of four replications, three irrigation methods, and total of four soil depths.

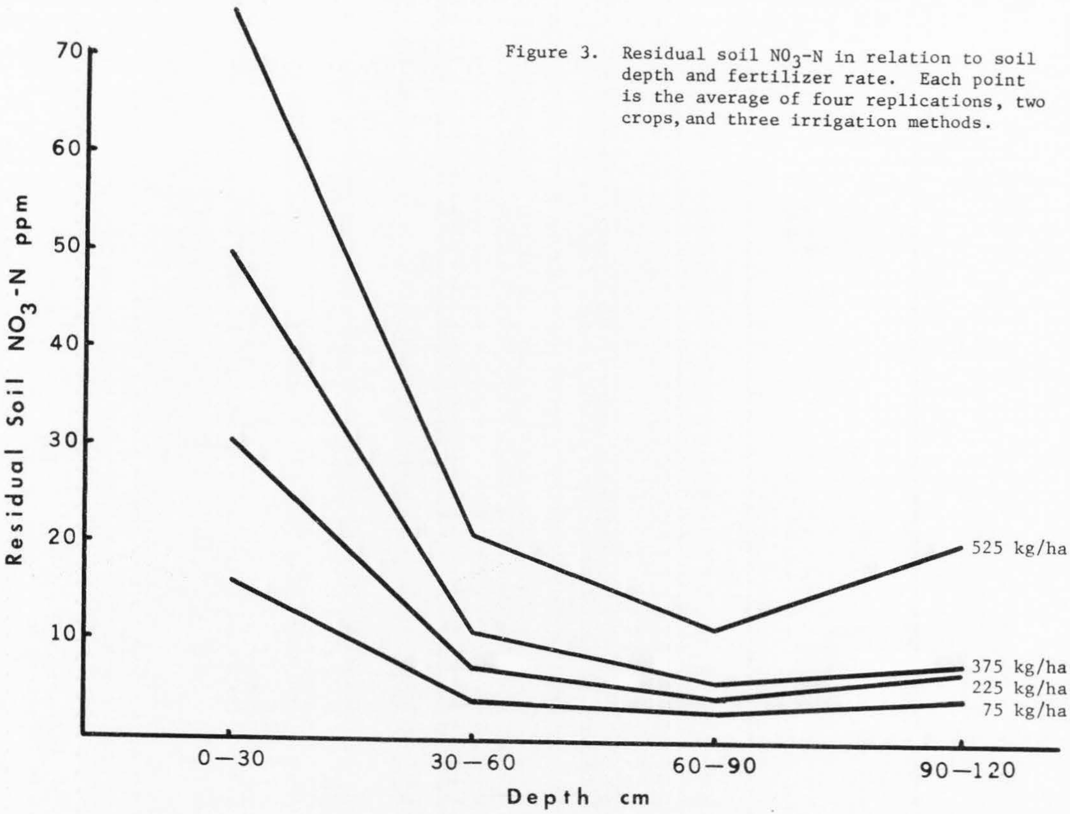

Figure 3. Residual soil NO_3-N in relation to soil depth and fertilizer rate. Each point is the average of four replications, two crops, and three irrigation methods.

in concentration in the lower three depth intervals. The greatest accumulation of NO_3-N was at the highest rate of fertilizer application (525 kg/ha) 124.7 ppm, decreasing with rate of fertilizer to the lowest rate (75 kg/ha) 27.2 ppm. Figure 4 demonstrates the linear relationship between residual NO_3-N and fertilizer application rate for the 30 cm depth only. For these data the correlation coefficient (r) is .99. Under the soil and climatic conditions at this experimental site and the additional benefit from measuring residual NO_3-N beyond the first 30 cm depth, or some other reasonable depth, might not justify the additional expense of sampling and laboratory analysis. White, Dumenil, and Pesek (1958) and White and Pesek (1959) in Iowa, under non-irrigated conditions, found soil sampling to the 21 cm layer gave high correlations between residual NO_3-N and oat yields.

Table 1. Residual soil NO_3-N in soil samples obtained May 1 at San Andres Experiment Station. A field experiment involving corn and tomatoes, three irrigation methods and four N rates had just been conducted

Soil depth	Nitrogen rate kg/ha 75	225	375	525	Average
cm	Soil NO_3-N ppm				
0- 30	15.79	30.41	50.13	72.12	42.11
30- 60	4.14	7.34	11.17	20.72	10.84
60- 90	2.81	4.21	6.10	11.41	6.13
90-120	4.44	7.54	8.13	20.51	10.15
TOTAL	27.19	49.49	75.53	124.75	

There was a significant difference in residual NO_3 between irrigation methods for Crop 2 as shown in Figure 5 (see Appendix A, Table 7).

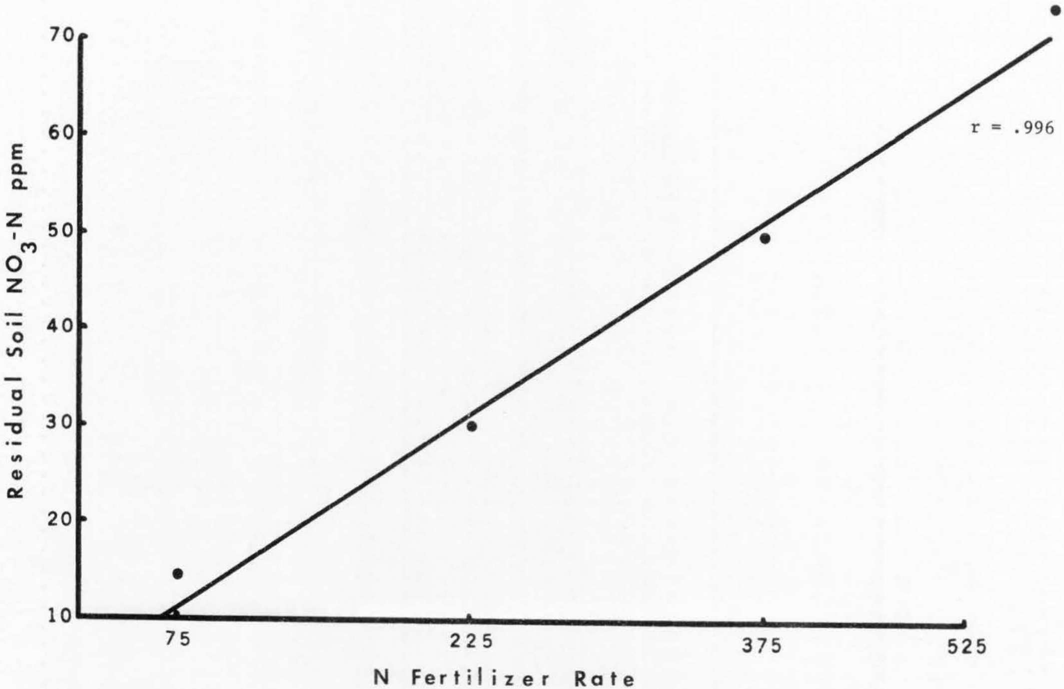

Figure 4. Residual NO_3-N in the 0-30 cm soil depth in relation to previously applied fertilizer N. Each point is an average of four replications, two crops, and three irrigation methods.

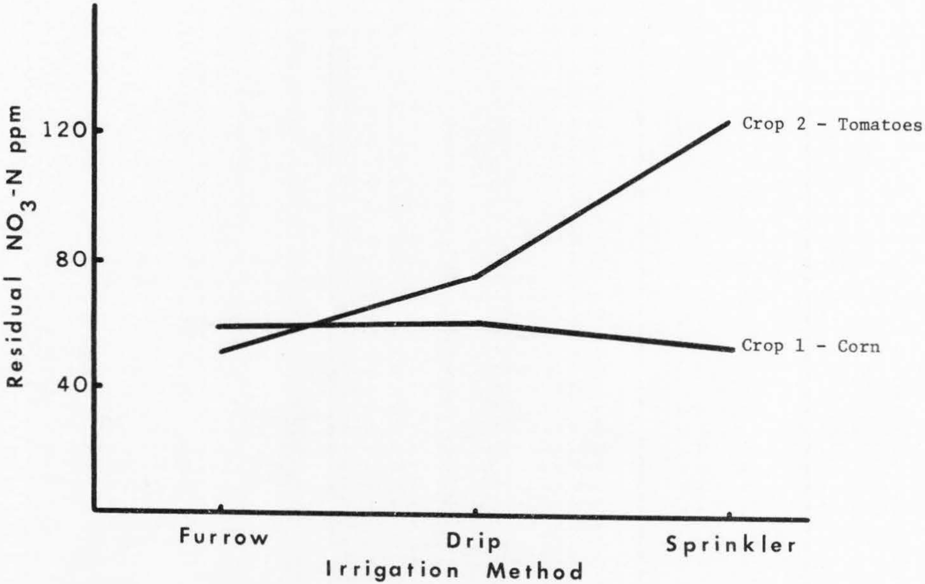

Figure 5. Residual soil NO_3-N as related to previous irrigation method and crop. Each point is the average of four replications, four fertilizer treatments, and total of four soil depths.

There was no significance with Crop 1, Figure 5. Table 2 shows the total amount of water applied by irrigation method to each crop during the irrigation season experiment. The average amount of water by the three methods for Crop 1 was 40.0 cm, for Crop 2 it was 41.0 cm. These data are shown to indicate that the total amount of water applied does not logically account for the difference in residual NO_3-N between the irrigation methods for Crop 2. One possible explanation might be considered in connection with row spacing of tomatoes and irrigation method. The tomato rows were 120 cm apart. For adequate irrigation by furrow, two furrows were made between tomato rows because of this concentration of water between the rows, some leaching beyond the 120 cm soil depth might have taken place. The soil is a sandy loam with coarse sand underlaying, therefore, the vertical movement of water could be quite rapid. Yield of the tomatoes might also have influenced the amount of residual NO_3-N by irrigation method. The average yields of the tomato crop were 39,302 kg/ha for the furrow method; 34,643 kg/ha for the drip method, and 32,911 kg/ha for the sprinkler method. The higher yield for the furrow irrigation method would indicate a higher usage of N by the crop and therefore less residual soil NO_3-N. For the drip irrigation method, one drip line was used for each crop row. For the corn crop with row spacing of 80 cm, this one line per row was sufficient. For the tomatoes, spaced at 120 cm, the water input would again be concentrated in a relatively small surface area and the opportunity for leaching would be less. It would be expected that the residual soil NO_3-N under the sprinkler method of irrigation would be slightly greater than that under the drip method because of the lower yield of tomatoes, but the large difference shown is unaccountable.

Table 2. Total amount of water applied by irrigation method during previous dry season

Crop	Method of irrigation			
	Furrow	Drip	Sprinkler	Ave.
	cm water			
Corn	38.7	45.0	36.2	40.0
Tomatoes	48.7	37.7	36.5	41.0

Figure 6 shows the concentration of NO_3-N in the four soil depth increments. In the first 30 cm with Crop 2, there were 15 ppm more NO_3-N than Crop 1. This difference decreased to 0 at soil depth 60 cm, then increased again to 6.5 ppm in favor of Crop 2 at 120 cm depth. This suggests that though there might be some leaching beyond the 120 cm depth for both crops, it probably would be greater for Crop 2. This could be accounted for to some extent by irrigation methods.

Soil sample analysis for NO_3-N taken at harvest time of the non-irrigated corn crop (Time 2) were 11.6, 12.5, and 11.1 ppm NO_3-N for the respective previously applied (Time 1) fertilizer N rates (i.e., N rates to 525 kg/ha). These low and constant amounts of NO_3-N demonstrate that there were no effects from Time 1 fertilizer N rates at the end of Time 2. It is reasonable to conclude that the NO_3-N measured by soil test at the wet season harvest time was derived from N mineralization of organic residues. These data are given in detail in Appendix C.

Corn yield response to residual NO_3

Table 3 and Figure 7 show the corn yield response during the rainy season (Time 2) to residual NO_3 from fertilizer applications

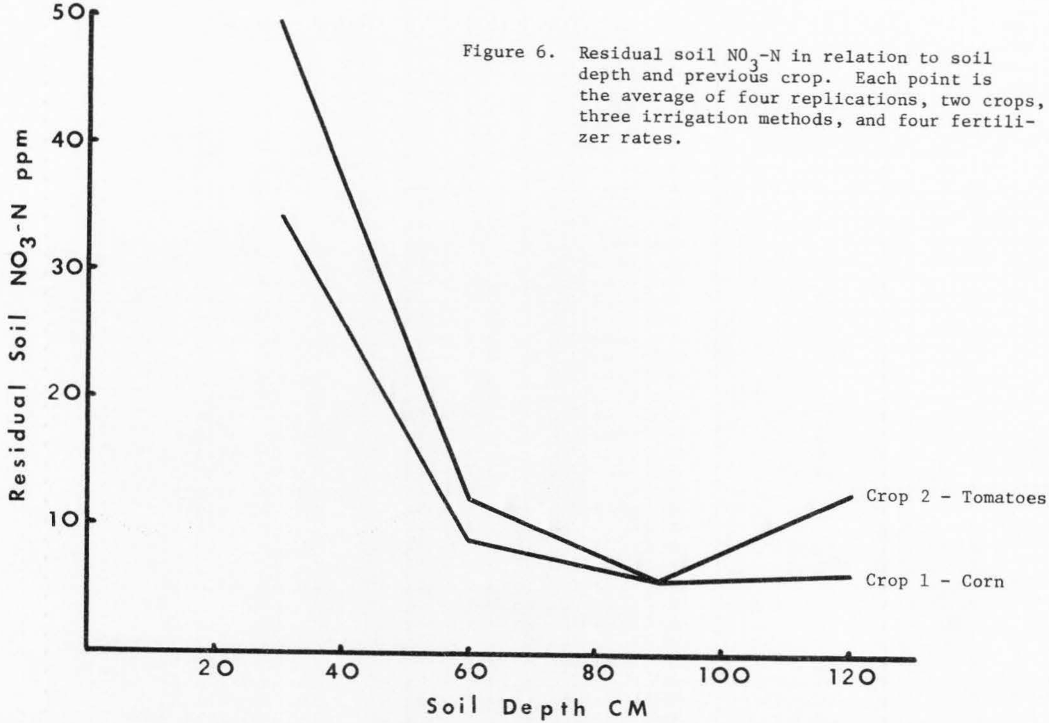

Figure 6. Residual soil NO_3-N in relation to soil depth and previous crop. Each point is the average of four replications, two crops, three irrigation methods, and four fertilizer rates.

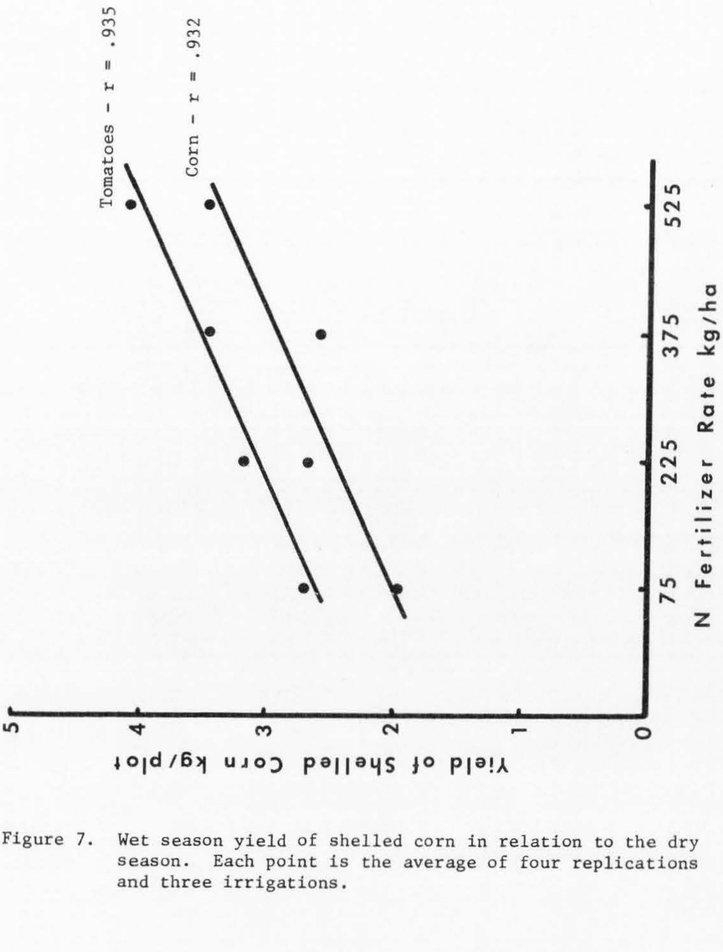

Figure 7. Wet season yield of shelled corn in relation to the dry season. Each point is the average of four replications and three irrigations.

Table 3. Wet season yield of shelled corn at 12 percent moisture as influenced by residual soil NO_3 from two crops and four fertilizer N rates during the previous dry season

Previous crop	Previous N rate kg/ha					
	75	225	375	525	Total	Ave.
	------------------corn yield kg/ha---------------------					
Corn	2.66	3.20	3.22	4.19	13.27	3.32
Tomatoes	1.96	2.71	2.65	3.55	10.87	2.72

at the beginning of the irrigation season (Time 1). The correlation coefficient shown in Figure 7 following Crop 1 is .935 and following Crop 2 is .932. It is interesting to note that even though plot yields were extremely low (1,037 and 850 kg/ha of corn, respectively, from Crop 1 plots and Crop 2 plots) the yields for both sets of plots increased with rate of fertilizer and therefore with soil NO_3-N (see Appendix A, Table 2). Leggett (1959), Nelson, Early, and Mortensen (1965; 1965; 1966), and James (1971) also found high correlations between residual soil NO_3-N and corresponding yields. The low corn yield was obviously the result of N deficiency. This was due to the heavy rains before and following planting.

Harmsen and Kalenbrander (1965) discuss the vertical downward displacement of N in soils as follows: The vertical downward displacement of nitrogen in sandy soils, beginning with field capacity was about 45 cm per 100 mm of rainfall entering the surface, about 30 cm in soils with 20-40 percent of the particles less than 20 microns in diameter, and only about 20 cm per 100 mm of rainfall for heavy clay soils. Assuming that these data apply, the precipitation (average of 155 mm for May) in the sandy Zapotitan soil would move the nitrogen to a depth of 60 cm. This rapid vertical movement of N largely explains the N deficiency of the growing corn. The benchmark corn yield from within the confines of the experimental area, as referred to in the procedure, was 8.89 kg per plot as compared to a maximum of 4.2 kg per plot (Figure 7) with residual NO_3-N alone.

Figure 8 shows rainy season (Time 2) corn yields as related to previous irrigation method and crop. Yields from Crop 2 plots responded to the irrigation method in the same manner as the residual NO_3-N. Crop 1 behavior was somewhat erratic although the yields from furrow and sprinkler plots did maintain the same relationship as with residual NO_3-N (see Figure 5). Figure 8 also shows an interaction between previous crops and methods of irrigation on Time 2 yields. The yield from the corn drip method of irrigation broke the pattern with residual NO_3-N. This effect makes the interaction, though statistically significant, of doubtful consequence.

The over-all corn yield in the rainy season experiment (Time 2) increased with increased residual NO_3-N. This response is demonstrated in Figure 9 which shows a correlation of .962. Figure 9 also shows correlation between corn yield and NO_3 found in the surface 30 cm only. This correlation is .94. It is obvious from the yields shown that the corn was not able to satisfy its N requirement from the residual NO_3-N alone. Figure 9 demonstrates that maximum yields were not obtained since yields did not level off as residual NO_3-N increased to the maximum measured level. The benchmark yield of 8.89 kg/plot gives further emphasis to this fact.

Residual soil NO_3-N as determined by soil test can be used as an index for estimating nitrogen fertilizer needs for corn. This is

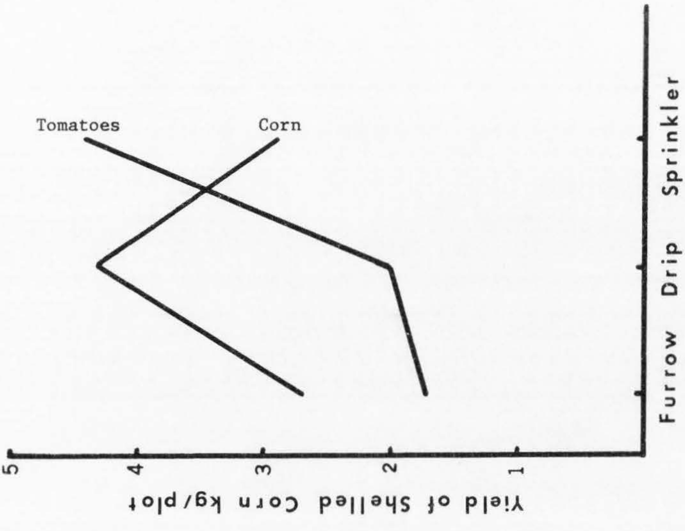

Figure 8. Shelled corn yield in relation to previous irrigation method and crop. Each point is the average of four replications and four fertilizer rates.

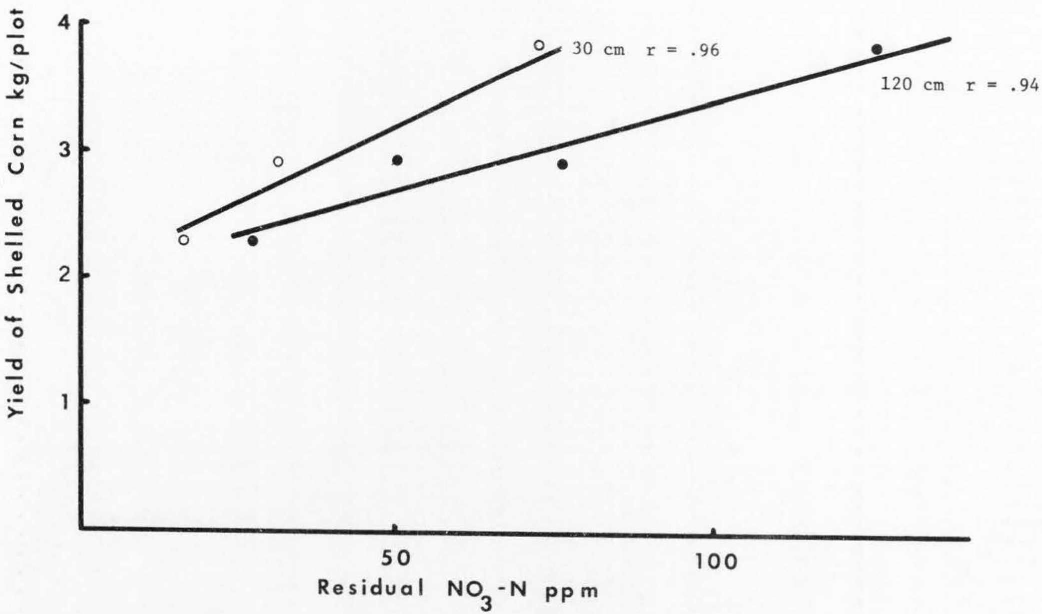

Figure 9. Yield of shelled corn in relation to residual NO_3-N at 30 cm *vs* 120 cm soil depth. Each point is the average of four replications, two crops, three irrigation methods, and four fertilizer treatments for the 30 cm soil depth. The 120 cm depth includes the sum of four soil depths.

demonstrated by Figure 9. Evidently, the added information with the deeper sample does not justify the effort of deep sampling and analysis. This idea was suggested previously in Figure 3. The efficiency of N was low because of leaching during the rainy season. However, in a year-round cropping program there will be some residual fertilizer that can be utilized and the efficiency of fertilizer use can be improved by soil test N to estimate the residual N.

As noted previously, benchmark corn yield for the rainy season was 8.89 kg/plot or 2,778 kg/ha. It is interesting to note in passing that under these experimental conditions it would have taken about 490 ppm of residual NO_3 to obtain the benchmark yield level. During the rainy season in the Zapotitan Valley N use efficiency is low apparently because of leaching. Good management practices for efficient use of fertilizer N are important. The benchmark yield equivalent of 2,778 kg/ha of corn was obtained using a total of 200 kg of N/ha applied in three equal applications.

SUMMARY AND CONCLUSIONS

In the Zapotitan Valley near San Andres, El Salvador, Central America, an experiment was designed to determine the amount and availability of residual soil N to corn during the rainy season. An experiment done during the preceding dry season was used as the basis. The variables of the dry season experiment were irrigation method, crop, and rate of fertilizer N application. Residual soil NO_3-N and NH_4-N in parts per million were determined by soil sample analysis to a soil depth of 120 cm by 30 cm depth increments. The soil samples were taken at the end of the dry season experiment. Yields were measured from corn grown during the rainy season.

The results indicate:

1. The measured residual soil NO_3-N taken at the end of the dry season experiment increased with the increased rate of fertilizer application while the measured residual soil NH_4-N remained constant and low. Therefore, NO_3-N alone contained all the information on residual N.
2. The residual soil NO_3-N increased with increased rate of N fertilizer application.
3. Corn yields were dependent on residual N from the previous season. These yields increased linearly with the increase of measured residual N. The highest yield was 47 percent of the benchmark yield.

4. During the rainy season in the Zapotitan Valley, N use efficiency is low due to leaching. Under these conditions fertilizer management is important and N should be made available to the crop in split applications in amounts and at intervals to satisfy crop requirements and minimize losses by leaching.
5. Soil samples were taken to a depth of 120 cm by increments of 30 cm. The relationship of the NO_3-N contained in the surface cm was parallel to that contained in the total 120 cm. Since the principle part of NO_3-N was contained in the surface 30 cm, this soil depth increment is sufficient to estimate the residual NO_3-N.
6. The results obtained from this experiment conducted under wet-dry tropical conditions support work done on residual N evaluation in a temperate zone (USA). The results demonstrate the applicability of these procedures under widely varying climatic conditions. It is concluded, therefore, that the measurement of NO_3-N can increase the efficiency of N fertilizer use in a year-round cropping system.

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APPENDICES

Appendix A

Residual soil N as NO_3 and NH_4 in ppm, in soil samples obtained April 22-30, 1973 at San Andres Experiment Station. A field experiment involving two crops, three irrigation methods, and four N fertilizer rates had just been concluded.

Table 4. Corn and furrow irrigation plots (N fertilizer rate kg/ha)

Replication	Soil Depth	75		225		375		525		Total		Average	
		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
	cm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	0-30	9.75	4.23	18.75	1.21	11.0	1.12	78.12	2.20	117.62	8.76	29.4	2.1
	30-60	2.44	.30	7.25	.31	5.75	1.25	17.81	1.88	33.25	3.74	8.3	.9
	60-90	1.75	2.12	3.19	2.42	3.88	.63	3.75	0.00	12.57	5.17	3.1	1.3
	90-120	2.19	0.00	5.56	.31	2.06	0.00	10.00	0.31	19.81	.62	5.0	.3
Total		16.13	6.65	34.75	4.25	22.69	3.00	109.68	4.39	183.25	18.29	45.8	4.6
2	1	12.38	2.20	23.12	0.31	48.75	0.61	72.80	0.00	157.05	3.12	39.3	.8
	2	3.19	0.00	5.25	3.93	15.62	0.31	16.81	9.07	40.87	13.31	10.2	3.3
	3	2.50	0.91	1.88	0.31	6.69	0.31	2.81	6.65	13.88	8.18	3.5	2.0
	4	1.50	0.31	1.38	0.16	6.50	4.08	8.62	0.00	18.00	4.55	4.5	1.1
Total		19.57	3.42	31.63	4.71	77.56	5.31	101.04	15.72	229.8	29.16	57.5	7.3
3	1	8.62	0.94	16.81	0.00	73.31	2.20	87.50	0.16	176.24	3.3	46.6	0.8
	2	4.62	0.16	18.25	21.47	6.87	0.00	27.81	0.31	57.55	21.94	14.4	5.5
	3	4.75	.31	11.62	3.93	4.75	1.57	4.67	1.51	25.74	7.32	6.4	1.8
	4	3.75	.31	5.73	3.33	3.31	0.30	12.38	1.57	25.19	5.51	6.3	1.4
Total		21.74	1.72	52.43	28.73	88.24	4.07	132.31	3.55	294.72	38.07	73.7	9.5
4	1	6.88	0.63	34.38	0.31	42.25	0.00	45.95	3.33	129.46	4.27	32.4	1.1
	2	1.62	4.39	5.37	1.21	4.00	1.51	41.25	17.54	52.24	24.65	1.31	6.2
	3	1.12	0.31	2.94	0.31	6.50	0.00	9.19	6.05	19.75	6.67	4.9	1.7
	4	1.75	1.81	2.00	0.31	2.31	6.96	8.00	0.31	14.06	9.39	3.5	2.3
Total		11.37	7.14	44.69	2.14	55.06	8.47	104.39	27.23	215.51	44.98	53.9	11.2

Table 5. Corn and drip irrigation plots (N fertilizer rate kg/ha)

Replication	Soil Depth	75		225		375		525		Totals		Average	
		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
	cm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	0-30	4.44	2.72	26.88	5.33	13.19	1.57	33.31	0.60	77.82	10.22	19.5	2.6
	30-60	5.95	1.81	8.94	0.60	15.62	1.21	8.00	2.79	38.51	6.39	9.6	1.7
	60-90	5.06	1.51	2.56	0.31	14.12	0.30	8.94	5.33	30.69	7.45	7.7	1.9
	90-120	6.69	0.00	3.06	0.31	.94	0.31	8.00	0.30	18.69	.92	4.7	.2
Total		22.14	6.04	41.44	6.55	43.87	3.39	58.25	9.0	165.71	24.98	41.4	6.2
2	1	3.75	2.42	15.62	0.16	40.00	0.63	53.10	0.91	112.47	4.12	28.1	1.0
	2	0.69	1.51	5.75	0.00	7.25	0.31	7.25	1.21	20.94	3.03	5.2	.8
	3	5.06	0.00	5.75	0.00	5.94	1.57	4.44	0.30	21.19	1.87	5.3	.5
	4	17.50	1.51	6.25	0.30	4.44	3.14	10.00	0.31	38.19	5.26	9.5	1.3
Total		27.00	5.44	33.37	.46	57.63	5.65	74.79	2.73	192.79	14.28	48.2	3.6
3	1	8.62	.30	33.50	0.00	53.12	1.88	156.20	.16	251.44	2.34	62.9	.6
	2	7.25	.31	4.12	0.00	15.06	0.00	18.75	.31	45.18	.62	11.3	.3
	3	5.94	.16	4.12	0.31	7.25	0.16	27.81	.30	45.12	.93	11.3	.2
	4	9.12	2.77	9.50	0.63	6.12	0.00	40.00	.16	64.74	3.56	16.2	.9
Total		30.93	3.54	51.24	.94	81.55	2.04	242.76	.93	406.48	7.45	101.62	1.9
4	1	7.12	1.21	18.25	1.21	33.44	3.14	41.25	1.88	100.06	7.44	25.0	1.9
	2	7.25	0.00	8.62	2.20	4.12	.60	9.75	3.93	29.74	6.73	7.4	1.7
	3	5.25	.63	6.12	.30	2.94	.00	6.50	0.0	20.81	.93	5.2	.2
	4	5.56	1.21	4.88	1.81	2.50	1.51	8.62	6.35	21.56	10.88	5.4	2.7
Total		25.18	3.05	37.87	5.52	43.0	5.25	66.12	12.16	172.17	25.98	43.0	6.4

Table 6. Corn and sprinkler irrigation plots (N fertilizer rate kg/ha)

Replication	Soil Depth	75		225		375		525		Totals		Average	
		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
	cm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	0-30	15.06	17.84	36.25	9.07	29.70	1.21	51.55	7.56	132.56	35.68	35.3	8.9
	30-60	0.31	3.31	1.81	3.75	2.12	2.12	5.37	4.54	15.74	8.78	3.9	2.2
	60-90	2.06	9.98	2.50	0.00	5.06	1.51	0.75	5.14	10.37	16.63	2.6	4.2
	90-120	4.12	1.57	2.94	3.93	13.19	9.05	9.19	0.30	29.44	14.85	7.4	3.7
Total		24.55	29.70	45.00	14.81	51.70	13.89	66.86	17.54	188.11	75.94	44.7	19.0
2	1	6.50	0.60	22.20	3.02	45.95	0.00	70.60	0.60	145.25	4.22	36.3	1.1
	2	.56	3.33	6.88	9.37	31.25	0.00	12.62	7.56	51.31	20.26	12.8	5.1
	3	12.00	5.44	5.56	5.14	8.94	6.05	10.00	0.16	36.5	16.79	9.1	4.2
	4	0.00	0.91	5.56	0.19	6.69	0.30	15.06	6.05	27.31	7.45	6.8	1.9
Total		19.06	10.28	40.20	17.72	92.83	6.35	108.28	14.37	260.37	48.72	65.1	12.2
3	1	10.00	8.16	14.12	5.14	31.25	3.14	70.60	4.54	125.97	20.98	31.5	5.2
	2	1.00	6.05	0.37	0.30	4.12	8.16	11.00	0.00	16.49	14.51	4.1	3.6
	3	1.19	6.65	1.50	1.24	2.94	1.82	7.75	0.30	13.38	9.98	3.3	2.5
	4	2.00	1.51	1.88	5.75	6.06	3.33	12.70	0.00	22.64	10.59	5.7	2.6
Total		14.19	22.37	17.87	12.4	44.37	16.45	102.05	4.84	178.93	56.06	44.7	14.0
4	1	10.63	4.54	26.88	0.16	34.37	0.31	50.00	0.31	121.88	5.32	30.5	1.3
	2	3.88	0.31	5.06	5.44	13.62	0.16	26.87	2.51	49.43	8.42	12.4	2.1
	3	1.38	0.16	2.06	0.31	18.25	0.94	25.88	1.57	47.57	2.98	11.9	.7
	4	3.31	0.16	8.44	5.14	7.19	1.21	12.87	1.81	31.81	8.32	8.0	2.1
Total		19.2	5.17	42.44	11.05	73.43	2.62	115.62	6.2	250.69	25.04	62.7	6.3

Table 7. Tomato crop and furrow irrigation plots (N fertilizer rate kg/ha)

Replication	Soil Depth	75		225		375		525		Totals		Average	
		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
	cm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	0-30	4.25	2.42	11.62	2.72	63.50	2.72	33.44	9.98	112.81	17.84	28.2	4.5
	30-60	1.00	6.27	2.44	.60	4.65	0.0	16.06	4.08	24.15	10.95	6.0	2.7
	60-90	1.12	2.42	1.00	.91	.74	12.4	1.50	1.51	4.36	17.24	1.1	4.3
	90-120	2.06	0.0	1.38	.91	4.44	2.2	5.75	.31	13.63	3.42	3.4	.9
Total		8.43	11.11	16.44	5.14	73.33	17.32	56.75	15.88	154.95	49.45	38.7	12.4
2	1	3.19	1.51	16.81	1.21	7.5	1.18	65.95	0.6	93.45	4.5	23.4	1.1
	2	2.50	8.16	8.62	1.51	1.88	.60	13.62	5.14	26.62	15.41	6.7	3.9
	3	.37	.30	2.81	1.25	1.12	.91	3.31	.91	7.61	3.37	1.9	.8
	4	2.31	.60	1.81	2.42	0.0	4.84	0.0	12.69	4.12	20.55	1.0	5.0
Total		8.37	10.57	30.05	6.39	10.5	7.53	82.88	19.34	131.8	43.83	33.0	11.0
3	1	10.0	2.77	36.25	18.45	48.75	4.54	70.6	.91	165.6	26.67	41.4	6.7
	2	4.25	.60	4.62	.06	4.62	4.23	8.0	4.54	21.49	9.43	5.4	2.4
	3	1.00	1.21	3.31	13.0	1.31	7.86	4.4	5.75	10.01	27.82	2.5	7.0
	4	1.19	3.33	3.75	1.51	8.25	4.84	11.0	4.54	24.19	14.22	6.0	3.5
Total		16.44	7.91	47.93	33.02	62.93	21.47	94.0	15.74	221.3	78.14	55.3	19.6
4	1	3.44	3.93	35.60	2.12	61.85	7.16	63.5	6.05	164.39	19.26	41.1	4.8
	2	7.75	2.77	2.06	1.88	1.88	0.0	15.06	0.0	26.75	4.65	6.7	1.2
	3	0.81	1.51	1.50	1.81	1.75	4.54	2.5	6.65	6.56	14.51	1.6	3.6
	4	0.81	1.21	5.62	0.0	6.25	3.63	5.56	8.49	17.24	13.31	4.3	3.3
Total		12.81	9.42	43.78	5.81	71.73	15.33	86.62	21.17	214.94	51.73	53.7	12.9

Table 8. Tomato and drip irrigation plots (N fertilizer rate kg/ha)

Replication	Soil Depth	75		225		375		525		Total		Average	
		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
	cm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	0-30	18.25	4.08	31.25	12.69	31.25	3.63	68.10	3.45	145.85	23.85	37.2	6.0
	30-60	1.56	3.14	3.37	.31	5.06	3.45	14.56	5.02	24.55	11.92	6.1	3.0
	60-90	.69	3.63	1.00	0.00	.81	.16	3.19	6.48	5.69	10.27	1.4	2.6
	90-120	2.44	5.02	4.75	0.6	.69	.31	15.06	7.26	22.94	13.19	5.7	3.3
Total		22.94	15.87	40.37	13.6	37.81	7.55	100.91	22.21	202.03	59.23	50.5	14.8
2	1	8.12	3.45	18.25	1.25	87.50	5.14	80.94	7.56	194.81	17.4	48.7	4.4
	2	1.62	0.31	2.44	3.93	2.56	.63	18.25	12.69	24.87	17.56	6.2	4.4
	3	0.0	.30	.56	6.35	5.94	6.65	.31	1.88	6.81	15.18	1.7	3.8
	4	5.06	.31	4.06	.63	12.75	.94	91.25	4.70	113.12	6.58	28.3	1.6
Total		14.80	4.37	25.31	12.16	108.75	13.36	190.75	26.83	339.61	55.72	84.9	14.2
3	1	12.87	1.88	33.31	0.63	91.25	0.60	34.81	6.27	172.24	9.38	43.1	2.3
	2	2.31	1.81	4.12	4.08	5.94	1.10	6.25	0.31	18.62	7.3	4.7	1.8
	3	0.0	1.51	9.50	6.05	5.75	0.31	1.88	1.25	17.13	9.12	4.3	2.3
	4	3.06	.16	8.94	2.82	18.25	0.31	34.81	0.0	65.06	3.29	16.3	.8
Total		18.24	5.36	55.87	13.58	121.19	2.32	77.75	7.83	273.05	29.09	68.3	7.3
4	1	47.50	8.47	27.81	1.25	34.81	10.28	150.62	.31	260.74	20.31	65.2	5.1
	2	11.62	0.63	2.00	4.44	8.00	.31	16.19	.12	37.81	5.5	9.5	1.4
	3	3.06	1.31	1.00	1.88	3.06	3.33	3.44	0.0	10.56	6.52	2.6	1.6
	4	7.12	0.16	8.62	2.51	6.69	6.05	24.38	3.45	46.81	12.17	11.7	3.0
Total		69.30	10.57	39.43	10.08	52.56	19.97	194.63	3.88	355.92	44.5	88.9	11.1

Table 9. Tomato and sprinkler irrigation plots (N fertilizer rate kg/ha)

Replication	Soil Depth	75		225		375		525		Total		Average	
		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
	cm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	0-30	53.15	20.56	10.20	3.02	75.30	6.65	87.50	4.84	228.15	35.07	57.0	8.8
	30-60	10.0	6.65	1.88	2.12	13.19	2.47	63.50	0.0	88.57	11.19	22.1	2.8
	60-90	3.56	9.98	5.06	8.17	3.06	4.84	15.06	1.21	26.74	24.2	6.7	6.1
	90-120	2.31	1.82	5.25	0.61	11.00	.91	48.75	12.10	67.31	15.44	16.8	3.9
Total		69.02	39.01	24.39	13.92	102.55	14.82	214.81	18.15	410.77	85.55	102.7	21.4
2	1	41.25	4.23	55.00	9.68	80.95	.61	91.25	1.21	268.45	15.73	67.1	3.9
	2	6.50	0.00	11.30	4.54	51.55	4.23	38.75	1.81	108.10	10.58	27.0	2.6
	3	5.56	0.0	10.00	0.91	14.56	7.86	7.75	0.30	37.87	9.07	9.5	2.3
	4	17.50	5.74	5.37	1.51	15.06	0.30	14.56	0.30	52.49	7.85	13.1	2.0
Total		70.81	9.97	81.67	16.64	162.12	13.00	152.31	3.62	466.91	43.23	116.7	10.8
3	1	63.50	0.61	84.05	8.17	72.80	6.65	80.95	8.77	301.3	24.2	75.3	6.1
	2	7.42	0.30	48.75	0.30	8.25	1.81	25.67	0.30	79.74	2.71	19.9	.7
	3	2.69	1.21	6.88	3.63	4.88	1.21	47.50	0.30	61.95	6.35	15.5	1.6
	4	4.00	5.75	9.19	8.77	9.19	0.0	35.60	0.30	57.98	14.82	14.5	3.7
Total		77.31	7.87	148.77	20.87	95.12	9.67	179.67	9.67	500.97	48.08	125.2	12.0
4	1	9.75	1.82	80.95	.61	91.25	.91	91.25	.91	273.2	4.25	68.3	1.1
	2	1.38	1.81	5.37	1.21	33.45	.30	68.10	7.86	108.3	11.18	27.1	2.8
	3	0.56	1.21	8.62	.61	16.19	.91	70.60	1.81	95.97	4.54	24.0	1.1
	4	1.31	2.42	65.95	7.56	41.25	3.33	50.00	3.33	158.51	16.64	39.6	4.2
Total		13.0	7.26	160.89	9.99	182.14	5.45	279.95	13.91	635.98	36.61	159.0	9.2

Table 10. Analysis of variance for residual N for data shown in Tables 4 and 6

Source	Variable[a]	DF	SS	MS	F
Replication (R)	1	3	2171.65	723.88	2.67
	2	3	49.11	16.37	1.07
	3	3	1723.85	574.61	2.18
Crop (C)	1	1	3560.70	3560.70	13.17**
	2	1	121.23	121.23	7.53*
	3	1	5060.58	5060.58	19.22**
Irrigation Method (I)	1	2	6198.33	3099.17	11.42**
	2	2	96.66	48.33	3.00
	3	2	7253.11	3626.56	13.78**
CI	1	2	7275.95	3637.97	13.40**
	2	2	50.85	25.42	1.58
	3	2	6171.64	3085.82	11.72**
Error A	1	15	4071.95	271.46	
	2	15	241.37	16.09	
	3	15	3948.56	263.23	
Fertilizer N (F)	1	3	21676.91	10558.97	39.02**
	2	3	32.83	10.94	0.87
	3	3	32536.62	10845.54	36.03**
CF	1	3	460.94	153.64	0.57
	2	3	7.46	2.48	0.198
	3	3	602.48	200.82	0.67
IF	1	6	857.73	142.95	0.53
	2	6	110.41	18.40	1.46
	3	6	526.53	87.75	0.29
CIF	1	6	1357.91	226.31	0.84
	1	6	16.28	2.71	0.22
	3	6	1311.30	218.55	0.73

Table 10. Continued

Source	Variable[a]	DF	SS	MS	F
Error B	1	54	14613.12	270.61	
	2	54	677.83	12.55	
	3	54	16256.65	301.04	
Depth (D)	1	3	79974.65	26658.22	131.01**
	2	3	68.14	22.71	1.08
	3	3	84707.18	28235.73	138.78**
Error C	1	9	1831.37	203.48	
	2	9	189.46	21.05	
	3	9	1828.47	203.16	
CD	1	3	3132.13	1044.04	6.87**
	2	3	80.37	26.79	2.69
	3	3	3890.43	1296.81	7.67**
ID	1	6	1300.21	216.70	1.42
	2	6	51.80	8.63	0.87
	3	6	1752.26	292.04	1.73
CID	1	6	1956.81	326.13	1.55
	2	6	47.99	7.99	0.80
	3	6	1872.97	312.16	1.85
FD	1	9	19738.51	2193.16	14.43**
	2	9	116.98	12.99	1.31
	3	9	18092.82	2010.31	11.89**
CFD	1	9	1398.06	155.34	1.02
	2	9	125.17	13.90	1.40
	3	9	1652.10	183.56	1.09
IFD	1	18	3198.500	177.69	1.17
	2	18	118.75	6.59	0.66
	3	18	3649.15	202.73	1.20
CIFD	1	18	1428.558	79.36	0.52
	2	18	137.23	7.62	0.77
	3	18	1816.31	100.90	0.60
Error D	1	207	31466.90	152.01	

[a]Variable 1 is NO_3-N; Variable 2 is NH_4-N, and Variable 3 is NO_3-N + NH_4N.

Appendix B

Yield of shelled corn, at 12 percent moisture, in kilograms per plot harvested October 23, 1973 at San Andres Experiment Station. A field experiment to estimate corn yield response to residual soil NO_3-N from a preceeding experiment involving two crops, three irrigation methods, and four fertilizer rates.

Table 11. Corn by furrow irrigation

Replication	N rates kg/ha			
	75	225	325	525
	--------------------kg corn/plot------------------			
1	1.28	2.46	2.41	6.33
2	2.72	4.17	3.11	2.86
3	1.98	3.64	1.49	2.46
4	1.49	2.71	1.41	3.54
Total	7.47	12.98	8.42	15.19

Table 12. Corn by drip irrigation

Replication	N rates kg/ha			
	75	225	325	525
	--------------------kg corn/plot------------------			
1	3.77	3.76	2.88	2.49
2	3.48	2.07	7.22	6.13
3	2.60	5.15	6.63	5.08
4	3.93	5.31	3.75	4.28
Total	13.78	16.29	20.48	17.98

Table 13. Corn by sprinkler irrigation

Replication	N rates kg/ha			
	75	225	325	525
	--------kg corn/plot--------			
1	2.58	1.72	2.18	3.30
2	2.06	1.38	1.59	3.62
3	2.28	1.94	1.94	3.84
4	3.75	4.03	4.04	6.32
Total	10.67	9.07	9.75	17.08

Table 14. Tomatoes by furrow irrigation

Replication	N rates kg/ha			
	75	225	375	525
	--------kg tomatoes/plot--------			
1	1.33	1.77	2.46	1.14
2	0.96	2.07	2.72	2.01
3	1.69	1.61	1.04	0.97
4	1.26	1.56	1.50	3.54
Total	5.24	7.01	7.72	7.66

Table 15. Tomatoes by drip irrigation

Replication	N rates kg/ha			
	75	225	375	525
	--------kg tomatoes/plot--------			
1	0.68	0.84	1.61	2.03
2	2.47	2.11	1.67	2.25
3	1.51	2.49	3.23	2.07
4	1.99	2.11	2.31	2.57
Total	6.65	7.55	8.82	8.92

Table 16. Tomatoes by sprinkler irrigation

Replication	N rates kg/ha			
	75	225	375	525
	----------kg tomatoes/plot----------			
1	3.98	3.72	1.55	9.84
2	2.54	5.69	2.50	8.41
3	2.34	3.47	5.13	2.80
4	2.75	5.14	6.04	4.95
Total	11.61	18.02	15.22	26.00

Table 17. Analysis of variance of soil NO_3-N at end of dry season

Source	DF	SS	MS	F
Replications	3	5.77	1.92	
Crop	1	8.60	8.60	4.77*
Irrigation	2	33.40	16.70	9.27**
CI	2	60.09	30.04	16.67**
Error A	15	27.03	1.80	
Fertilizer	3	29.66	9.88	6.17**
CF	3	0.16	.53	0.03
IF	6	16.08	2.68	1.67
CIF	6	10.33	1.72	1.07
Error B	54	86.53	1.60	

Appendix C

Table 18. Residual soil N as NO_3 and NH_4 in ppm, in soil samples obtained August 8-12, 1973 at San Andres Experiment Station. A field experiment involving corn grown during the rainy season had just been concluded (see Appendix A) (N fertilizer rate kg/ha)

Depth (foot)	Corn (drip)								
	75		225		375		525		Total
	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
1	7.75	6.65	5.87	6.65	5.87	4.23	4.75	3.33	24.24
2	2.12	2.12	1.50	.61	2.94	.91	2.12	.91	8.68
3	1.44	3.93	1.31	3.93	1.81	3.33	1.62	2.42	6.18
4	2.56	.91	1.31	1.51	1.81	.60	4.38	10.89	10.06
Total	13.87	13.61	9.99	12.70	12.43	9.97	12.87	17.55	49.16
	Corn (sprinkler)								
1	5.25	4.84	6.62	4.84	4.50	4.84	3.19	3.33	19.56
2	2.56	.30	3.19	2.42	4.38	.91	2.00	.91	12.13
3	2.50	2.42	2.81	2.72	2.81	2.42	1.81	5.14	9.93
4	2.69	10.89	2.94	2.42	2.81	1.21	1.50	1.51	9.94
Total	13.00	18.45	15.56	12.40	14.50	9.38	8.50	10.89	51.56
	Corn (furrow)								
1	4.25	4.84	4.38	6.05	4.06	5.14	0.00	4.23	12.69
2	2.00	.91	1.88	1.81	1.88	.91	1.69	1.51	7.45
3	5.25	3.02	1.44	4.23	1.50	2.12	2.25	1.51	10.44
4	1.69	3.02	1.19	0.00	3.94	0.00	4.50	1.21	11.32
Total	12.19	11.79	8.89	12.09	11.38	8.17	8.44	8.46	41.90

Table 18. Continued

Depth (foot)	Tomatoes (drip)								
	75		225		375		525		Total
	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3	NH_4	NO_3
1	3.00	3.02	2.12	2.72	3.94	4.23	2.81	.60	11.87
2	2.56	3.02	2.12	.30	2.50	1.51	2.69	.60	9.87
3	2.12	2.12	1.81	1.81	2.00	1.21	2.38	1.81	8.31
4	2.56	.91	2.00	.30	2.38	2.42	2.38	1.51	9.32
Total	10.24	9.07	8.05	5.13	10.82	9.37	10.26	4.52	39.37
	Tomatoes (sprinkler)								
1	3.44	5.14	3.81	3.93	3.56	3.93	4.06	6.96	14.87
2	2.38	3.33	2.38	2.72	2.38	2.42	2.81	2.42	9.95
3	2.12	4.23	2.00	0.00	2.38	4.84	2.94	5.44	9.44
4	1.88	.91	1.81	0.00	4.06	2.42	2.81	0.00	10.56
Total	9.82	13.61	10.00	6.65	12.30	13.61	12.62	14.82	44.82
	Tomatoes (furrow)								
1	4.25	3.93	4.38	5.14	6.62	6.96	5.75	.30	21.00
2	1.88	.91	2.81	7.86	3.19	4.84	2.81	4.84	10.69
3	1.50	5.14	2.38	4.84	1.69	0.00	2.50	3.63	8.07
4	1.69	2.72	1.69	.30	2.25	.30	3.00	1.81	8.63
Total	9.32	12.70	11.25	18.14	13.75	12.10	14.06	10.58	48.38
	69.44	79.23	63.74	67.11	75.26	61.70	66.75	66.82	275.19
Average Total	11.57	13.21	10.62	11.19	12.54	10.28	11.13	11.14	11.47